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CORRELATION OF EXPOSURE AND POTENTIAL SOLAR RADIATION TO PLANT FREQUENCY OF *AGROPYRON DESERTORUM*[1]

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Abstract. The hypothesis that exposure and potential solar beam radiation are useful parameters in describing frequency response of a monoculture bunchgrass was tested. Slope, aspect [sine (azimuth angle +68°)]; and daily potential solar beam radiation (June 22) accounted for 18%, 8% and 13%, respectively, and 22% collectively, of the variation in *Agropyron desertorum* plant frequency. Maximum plant numbers occurred on south- to-west exposures, but these exposures had more steeply inclined slopes and actually received less potential solar radiation than others during the summer solstice. Aspect data alone are inadequate for interpreting plant response to soil moisture, temperature, and solar radiation, especially when a wide range in slope is involved.

INTRODUCTION

South-oriented exposures (northern hemisphere) receive more radiation and are relatively more xeric than north exposures. The often observable differences in microclimate on different exposures occur because of radiation effects on soil temperature and water content. The differences between dominating grass species on various exposures were attributable to soil temperature and soil moisture gradients, which in turn were related to aspect and slope (Dix 1958; Harper and Ludwig 1968).

Aspect and slope parameters have frequently been useful in describing site-vegetation relationships (Klemmedson 1964; and Medin 1960). Incident radiation, however, may be a more useful parameter, but such data are seldom available where multiple aspects and slopes are being studied. Some investigators have incorporated either instantaneous or average solar radiation potentials (Ayyad and Dix 1964; Nash 1963; and Scott and Billings 1964). These values are calculated from the solar constant (2.00 cal/cm^2/min) by adjusting for latitude, time of day and year, slope, and aspect. Potential radiation is here defined as the maximum energy received on the earth's surface assuming that there is no atmosphere to reduce its intensity.

Potential radiation has been successfully used where different vegetation responses, i.e., species or growth, are visually evident because of moderate to steep slopes and varying exposure. The objective of this study was to test the hypothesis that exposure and the geometric parameter—potential daily solar beam radiation—correlate with frequency response of seeded *Agropyron desertorum* on moderate slopes. If a significant relationship exists, it could provide a simplified model of environment-plant interactions and serve as a first approximation for more detailed study.

TABLE 1. Plant occupancy as function of azimuth angle. The mean slope and number of sites are given for each cardinal point

Azimuth degrees	Direction	Plant Frequency No. per 100 sq. ft. $\bar{x}$	$\sigma_{\bar{x}}$	Mean slope (per cent)	No. of sites
0	N	39	±7	1.5	21
45	NE	34	8	2.8	11
90	E	24	7	3.6	13
135	SE	28	7	1.9	20
180	S	53	6	5.5	23
225	SW	43	6	5.0	16
270	W	58	7	3.8	10
315	NW	33	10	4.8	5
					$n = 119$

EXPERIMENTAL SITES AND METHODS

Artemisia-steppe vegetation sites that had been burned or tilled and then fall-seeded to *Agropyron desertorum* were selected on the Owyhee and Malheur uplands in southeastern Oregon. Physical site descriptors (Table 1) for the 119 sites ranged in value as follows: slope, 0 to 16 per cent ($\bar{x} = 3.6\%$); latitude, 42.0 to 44.5° north ($\bar{x} = 43.0°$), elevation, 1280 to 1620 m; and exposure, 0 to 315° (from north) azimuth. Plant frequency (Hyder and Sneva 1954) ranged from 0 to 94 plants per hundred sq ft ($\bar{x} = 40$). All sites had been deferred from grazing one year and ranged in age from 1 to 11 years ($\bar{x} = 4.7$).

Multiple correlation analysis was performed between plant frequency and the independent variables of slope, aspect, and daily potential solar beam radiation. The radiation values were interpolated from handbook values (Frank and Lee 1966). Morning radiation, both direct and diffuse is generally used to

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evaporate water, while afternoon radiation is used in heating the soil. Biological parameters may be more subject to the energy flux on south-to-west slopes than on other slopes. An optimization procedure locates the aspect at which this maximum response occurs, relative to the responses on other aspects. The trigonometric transform is applied in order to parallel the geometric solar radiation pattern. Aspect data were transformed as:

$$x_2 = 1 + \sin(\text{azimuth angle} + \alpha)$$

where α is rotated from 0 to 180° by increments of 22.5° to test for maximum orientation response. Radiation data for each of the 13 daily periods (15-day intervals) and the sum of six daily values dispersed between April 4 and June 22 were tested for correlation with plant frequency.

Results

Simple correlation analysis showed that of the variation in plant frequency, 18 per cent was associated with similar variation in slope ($r = 0.43$), 8 per cent with a sine transform of aspect ($r = -0.28$), and 13 per cent with an inverse of daily potential radiation on June 22 ($r = -0.36$). The coefficient of determination of plant frequency on slope, aspect, and potential radiation was $R^2 = 0.22$ and when slope was excluded $R^2 = 0.19$.

Transformed aspect data correlated best with plant frequency for $\alpha = 67.5°$ equivalent to an azimuth angle of 202.5° and a south-southwest exposure.

Plant frequency was inversely related to daily potential radiation from May through August and the best fit was calculated for June 22 values. Correlation values for other periods decreased for days farther removed from June 22 until they were zero in April and September and then positive, but not significant, during the winter months. Plant frequency had a significant negative correlation with the sum of daily potential values for the six periods April through June.

Discussion

Multiple correlation analysis of slope, aspect and potential radiation accounted for only 22 per cent of the variation in *A. desertorum* frequency. A large part of the variation in frequency was still unaccounted for and must relate to antecedant soil moisture at seeding time and other edaphic and climatic factors.

The site-vegetation analysis predicted that plant frequency increased with slope and was maximum on south-to-west aspects. This relationship of aspect appears to conflict with the hypothesis that south-southwest slopes are the warmest and driest (Geiger 1965) and thus the least hospitable for plants. It is here that the third parameter, potential solar radiation, helps to draw a meaningful conclusion.

A horizontal surface on June 22 accumulates more daily radiation than any other exposure at that latitude and values decrease as slope increases for given aspects (Frank and Lee 1966). Thus, in this study the slopes on the south-to-west exposures ($\bar{x} = 5$ per cent) received about 2 per cent less potential radiation than did the other exposures whose average slope was 2 per cent. It is therefore concluded that these south-to-west slopes may be more mesic than was first thought when considering aspect orientation alone. This is further substantiated by the significant negative correlation between slope and potential radiation ($r = -0.84$).

The relationship of potential radiation and exposure to plant frequency has been suggested here as a direct effect of soil temperature and ultimately soil water on plant survival. However, casual factors increasing plant numbers on south-to-west exposures might include warmer soils during fall germination and during early spring growth, reduced afternoon radiation because of cloudiness or slightly favored amounts of spring precipitation since storms arrive from a southwesterly direction. Their effects, even if small, are nevertheless additive in favoring higher plant frequencies on south-to-west exposures. Other important site factors relating to soil temperature and water content include reflection (albedo), surface temperature, and soil thermal diffusivity (Nunn, et al., 1971). These factors, however, require considerable instrumentation and are therefore beyond the objective of this study.

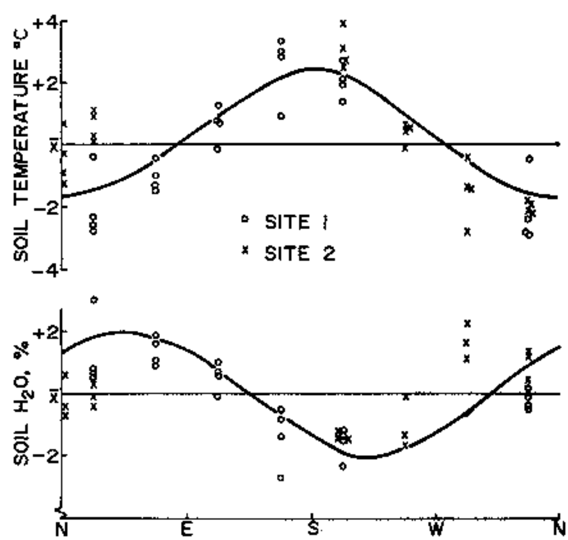

Fig. 1. Soil temperature and moisture deviation from mean as function of aspect on 13–18 per cent slopes of the Saskatchewan prairie. Figure adapted from data of sites 1 and 3, and dates May through September (Ayyad and Dix 1964). It is assumed that soil water content is mean of duplicate 0 to 15 and 15 to 30 cm depth soil samples while soil temperature is mean of 0.1, 15, and 30 cm depths calculated from $\geqq 6$, 3, and 3 replications, respectively.

A sinusoidal relationship is normally measured between aspect and other select physical and biological parameters. Soil water and temperature may fit such a relationship (Figure 1) and this may hold for potential daily or instantaneous solar radiation as well. However, the use of aspect in a site-vegetation index (in this study) may have led to possible misinterpretation of the indirect effects of potential radiation on soil temperature, soil water, and ultimately plant frequency. Selection of sites having a narrow range in slope such as reported by Ayyad and Dix (1964) may be helpful in avoiding misinterpretation of exposure and potential radiation parameter effects on biological and physical parameters.

Literature Cited

Ayyad, M. A. G., and R. L. Dix. 1964. An analysis of a vegetation-microenvironmental complex on prairie slopes in Saskatchewan. Ecol. Monog. **34**: 421–442.

Dix, R. L. 1958. Some slope-plant relationships in the grasslands of the Little Missouri badlands of North Dakota. J. Range Manage. **11**: 88–92.

Frank, E. D., and Richard Lee. 1966. Potential solar beam irradiation on slopes. U. S. Forest Serv. Res. Paper RM-18, 116 pp., illus.

Geiger, R. 1965. The climate near the ground. Harvard Univ. Press, Cambridge, Mass., 611 p.

Harper, K. T., and J. A. Ludwig. 1968. An evaluation of soil temperature as a factor in interpretive ecology. Bull. Ecol. Soc. Am. 49: 69.

Hyder, D. N., and F. A. Sneva. 1954. A method for rating the success of range seeding. J. Range Manage. **7**: 89–90.

Klemmedson, J. O. 1964. Topofunction of soils and vegetation in a range landscape. *In* Amer. Soc. Agron. Special Publ. No. **5**, pp. 176–189.

Medin, D. C. 1960. Physical site factors influencing annual production of true mountain mahogany *Cercocarpus montanus*. Ecology **41**: 454–460.

Nash, A. J. 1963. A method for evaluating the effects of topography on the soil-water balance. Forest Sci. **9**: 413–422.

Nunn, J. R., R. D. Burman, J. D. Armijo, L. O. Pochop, and C. F. Becker. 1971. Meterological characteristics of the shortgrass ecosystem. Univ. of Wyo., Agr. Exp. Sta. Res. J. No. **48**.

Scott, D., and W. D. Billings. 1964. Effects of environmental factors on standing crop and productivity of an alpine tundra. Ecol. Monog. **34**: 243–270.